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Dynamic Modeling of a Homogeneous Thorium Recycle in CANDU Reactors

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1. Introduction

A closed thorium fuel cycle has been modeled through a multiple recycling of a homogeneous thorium fuel in CANDU reactors. The multiple recycling is modeled by the dry process technology. The dry process considered in this study is a "thermo-mechanical process" developed for the direct use of spent PWR fuel in CANDU reactors (DUPIC) [1].

The homogeneous thorium-uranium (ThO_2-UO_2) fuel was designed to construct a closed fuel cycle. In the fuel cycle, the thorium and uranium are homogeneously mixed and burned in the reactor. The fission products are assumed to be removed from the spent fuel through the dry process and are mixed again with 20 wt% slightly enriched uranium (SEU) for the next fuel cycle. The fuel bundle was the CANFLEX fuel bundle which has 43 fuel elements.

In this study, the Korean nuclear fuel cycle scenario is analyzed based on a postulated homogeneous thorium cycle. Important fuel cycle parameters such as the amount of spent fuel, plutonium, minor actinides (MA) and fission products (FP) inventories are investigated and compared with that of the once-through fuel cycle. Parametric calculations are performed by the modified DYMOND code [2].

2. Fuel Cycle Model

The homogeneous ThO_2-UO_2 fuel was considered to construct a closed fuel cycle as schematically shown in Fig. 1. In this model, the required amount of uranium and thorium are calculated as follows:

$$M_{Th} = R_{Th-U} \cdot F_{Th} \quad (1)$$
$$M_{U} = R_{Th-U} \cdot F_{U} \quad (2)$$

where R_{Th-U} is a ThO_2-UO_2 fuel request, and F_{Th} and F_U are the ThO_2 and UO_2 fractions in the fresh fuel, respectively.

The feed is the difference between the required and recovered amount as follows:

$$FD_{Th} = M_{Th} - RC_{Th} \quad (3)$$
$$FD_{U} = M_{U} - RC_{U} \quad (4)$$

where RC_{Th} and RC_U are the recovered amount of ThO_2 and UO_2, respectively. The recovered amount can be calculated as follows:

$$RC_{Th} = D_{Th-U} \cdot (1-L) \cdot S_{Th} \quad (5)$$
$$RC_{U} = D_{Th-U} \cdot (1-L) \cdot S_{U} \quad (6)$$

where D_{Th-U} is a amount of the dry processed fuel, L is a loss factor of the dry process, and S_{Th} and S_U are the THO_2 and UO_2 fractions in the spent fuel, respectively.

In this homogeneous recycling model, the fission products are assumed to be completely removed from the spent fuel through the dry process and a feed of 20 wt% slightly enriched uranium (SEU) and thorium for the further fuel cycle. In this way, it is possible to keep most of the irradiated actinides in the reactor system throughout a plant's life time.

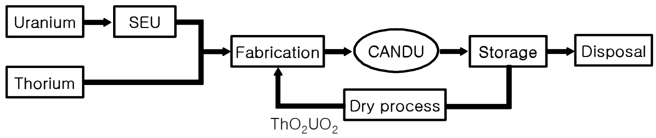

Fig. 1 Homogeneous Fuel Cycle Model

In the fuel cycle scenario, the nuclear power demand is expected to grow from 13.7 GWe in 2000 to 25.2 GWe in 2015 [3]. From 2016 to 2100, the nuclear capacity was assumed to be maintained at the same level as that of 2015. In 2000, there were 12 PWRs and 4 CANDU reactors in Korea, but there will be no more constructions of CANDU reactors after 2000. The reactor life-time was assumed to be 40 and 30 yrs for the PWR and CANDU reactor, respectively.

For the analysis of the fuel cycle with the thorium fuel, it was assumed that the dry processing of the PWR spent fuel begins in 2015 and the thorium fuel CANDU reactor is deployed from 2020. The life-time of the CANDU reactor with the thorium fuel was assumed to be 40 yrs and the electricity generation fraction of the thorium fuel CANDU reactor was assumed to be 30%.

3. Results and Discussion

From the once-through fuel cycle analysis results, the number of PWR in 2100 is expected to be 26 when the reactor power is 1.0 GWe. But the number of CANDU reactors becomes 0 after 2030. The SF inventory steadily increases with time and the total SF will be 65 kt in 2100. From 2030, the CANDU SF inventory remains constant at 9 kt. For the SF accumulated by 2100, the total amount of uranium and plutonium will be 62 kt and 0.6 kt, respectively. Also, the total amount of MA and FP will be 0.05 kt and 2.4 kt, respectively.

From the recycling scenario by the thorium fuel, the results are illustrated in Fig. 2, which shows the number of operating reactors. The PWR share of the electricity generation deceases and ultimately it goes down to ~70%, while the remaining thorium fuel CANDU reactors capacity increases to ~30% in 2100. The numbers of PWR and thorium-CANDU reactors are expected to be 19 and 12 in 2100, respectively.

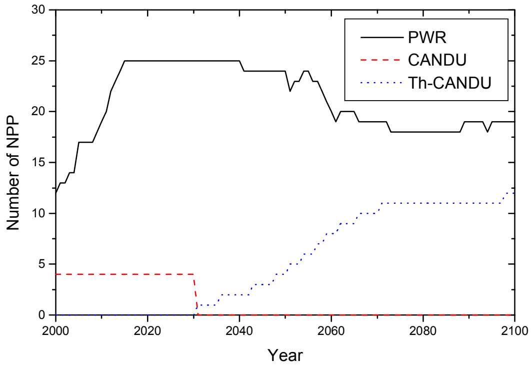

Fig.2 Number of operating reactor

Figure 3 compares the annual natural uranium mining between the once-through and thorium fuel cycles. It can be seen that the annual uranium mining of the thorium fuel cycle is lower after 2040 when compared to the once-through cycle. The total amount of uranium mining of the thorium cycle until 2100 is 389 kt which is lower by 15% when compared with the once-through cycle.

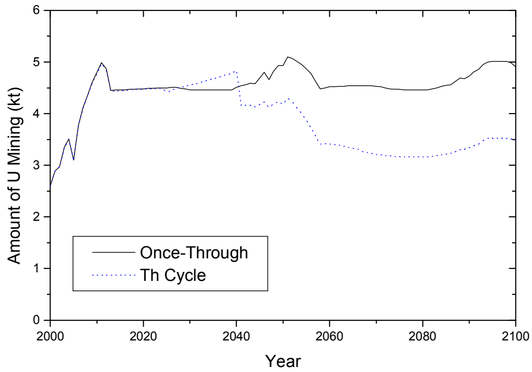

Fig.3 Comparison of annual uranium mining

Figure 4 compares the inventory of the SF for the thorium fuel recycle and once-through scenarios. The PWR SF decreases with time and becomes 49 kt, while the CANDU SF remains constant at 9 kt after 2030. With this inventory of the SF, the total amount of uranium, plutonium and MA in the SF will be 45, 0.7 and 0.07 kt, respectively. The total amount of FP including the processed FP will be 3 kt.

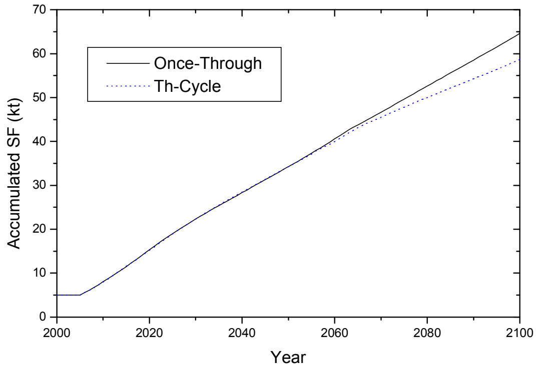

Fig. 4 Comparison of spent fuel accumulation

From the above results, it was found that the physical volume of the high level waste, which should be geologically disposed of, is reduced by ~10% in the thorium fuel CANDU cycle by recycling the thorium fuel. The amount of sensitive materials such as plutonium and MA is reduced by ~8%, when compared with the once-through fuel cycle. It is also shown that the amount of FP, which is known to have a short-term environmental effect, is not reduced much since the FP is continuously produced. Consequently, the thorium fuel CANDU cycle can slightly reduce the spent fuel inventory. This cycle can also contribute to a saving on the uranium resources.

ACKNOWLEDGEMENT

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